

**California Department of Transportation  
Division of Engineering Services  
Materials Engineering and Testing Services  
Corrosion and Structural Concrete  
Field Investigation Branch**

# **CORROSION GUIDELINES**

**Version 2.0**

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## **NOTICE**

The contents of this document reflect the views of Materials Engineering and Testing Services which is responsible for the facts and the accuracy of the guidelines presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. **These guidelines do not constitute a standard, specification, or regulation.**

Neither the State of California nor the United States Government endorses products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

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## **1. INTRODUCTION**

These guidelines outline the corrosion evaluation and recommendation aspects of site investigations for California Department of Transportation (Department) projects. The guidelines list the requirements for field investigations related to corrosion, including requirements for sampling of soil and water, required corrosion testing, reporting of results, requests for assistance, and corrosion mitigation measures (design alternatives).

This document is intended for use by Department staff and consultants, working on the Department's projects, performing field investigations related to corrosion, and/or providing design recommendations that include corrosion mitigation measures. This document supersedes the following report: *Corrosion Guidelines September 2003*. Additional Department guidelines such as the *Standard Specifications*, *Bridge Memo-To-Designers* and others can be found in the References section of this report.

## **2. THE DEPARTMENT'S FUNCTIONAL GROUPS ASSISTING WITH CORROSION INVESTIGATIONS**

This section outlines the roles and responsibilities of Department staff performing corrosion assessments of project sites. The District Materials Branches are responsible for preparing a Materials Report (MR) for all projects that involve pavement structural section recommendations or pavement studies, culverts or other drainage features, corrosion studies, materials, or disposal sites. This policy is defined in Chapter 600 of the *Highway Design Manual (HDM)* (<http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm>). The District Materials Branches collect soil and water samples for corrosion testing. They perform minimum resistivity and pH testing, but send samples to the Materials Engineering and Testing Services (METS), Corrosion and Structural Concrete Field Investigation Branch (CSCFI) for chloride and sulfate testing, if necessary. Documentation of the corrosion investigation, sampling, corrosion testing, and corrosion recommendations for culverts and drainage structures are the responsibility of the District Materials Branch. The CSCFI Branch can provide report assistance or review, if necessary.

Geotechnical Services (GS) is responsible for preparing reports for Structure Design to support design of structure foundations, special design retaining walls and buildings. GS also prepares reports for the District Project Engineer to support design of highways, standard plan structures, earthwork and related items not designed by Structure Design. Geotechnical investigations are required for projects involving cut slopes, embankments, earthwork, landslide remediation, retaining walls, sound walls, groundwater studies, erosion control features, sub-excavation, and any other studies involving engineering geology. As part of the geotechnical investigation, GS is responsible for conducting a corrosion investigation of the structure site. The corrosion investigation should include sampling of soil and water for corrosion testing, summarizing corrosion test data, and a discussion of the corrosivity of the project site.



Generally, corrosion mitigation measures for structures are selected by Division of Engineering Services (DES) design staff, using appropriate measures listed in Department guidelines. Additional assistance regarding selecting appropriate corrosion mitigation measures may be obtained from the CSCFI Branch if needed. Geotechnical Services staff does not routinely provide corrosion mitigation measures in their reports; however, they should be aware of corrosion mitigation requirements when recommending pile/foundation alternatives.

### **3. REQUIREMENTS FOR CONSULTANTS PROVIDING CORROSION ASSESSMENTS OF DEPARTMENT PROJECTS**

This section outlines the roles and responsibilities of consultants providing corrosion investigation services and corrosion mitigation recommendations for Department projects. In addition, this section can be used by Department staff providing consultant oversight of corrosion investigation services and mitigation recommendations prepared by consultants.

The flowchart at the end of this section outlines the roles and responsibilities of the various Department functional groups assisting consultants performing corrosion investigations, and lists the responsibilities of the consultant.

Foundation investigations are required for all structures (including bridges, tunnels, retaining walls, MSE walls, sound walls, tie-back walls, overhead signs, maintenance stations, pumping plants/stations, toll plazas, etc.). All foundation investigations require a corrosion investigation and evaluation. Preliminary and final Foundation Reports prepared by consultants should include all available corrosion data for the site and a brief discussion of the data. If corrosion data is not available, or is insufficient to provide conclusive information regarding the corrosivity of the site, then additional corrosion sampling and testing is required per Department guidelines during the field investigation phases.

Consultants should follow the recommendations for preparing reports as discussed in the following: *Caltrans Geotechnical Manual*

([http://www.dot.ca.gov/hq/esc/geotech/geo\\_manual/manual.html](http://www.dot.ca.gov/hq/esc/geotech/geo_manual/manual.html)),

*Guidelines for Preparing Geotechnical Design Reports Version 1.3 (December 2006)*

(<http://www.dot.ca.gov/hq/esc/geotech/requests/gdrguidelines20061220.pdf>), and the

*Foundation Report Preparation* document (December 2009)

([http://www.dot.ca.gov/hq/esc/geotech/requests/fr\\_preparation\\_bridge.pdf](http://www.dot.ca.gov/hq/esc/geotech/requests/fr_preparation_bridge.pdf)).

Consultants under contract to provide design related recommendations should include corrosion recommendations consistent with Department guidelines. Corrosion design recommendations should be based on the worse case test results from the site in accordance with Department guidelines. Sufficient information regarding the number and location of soil borings, sampling, and testing should be included to allow a thorough review of any corrosion recommendations by Department staff.



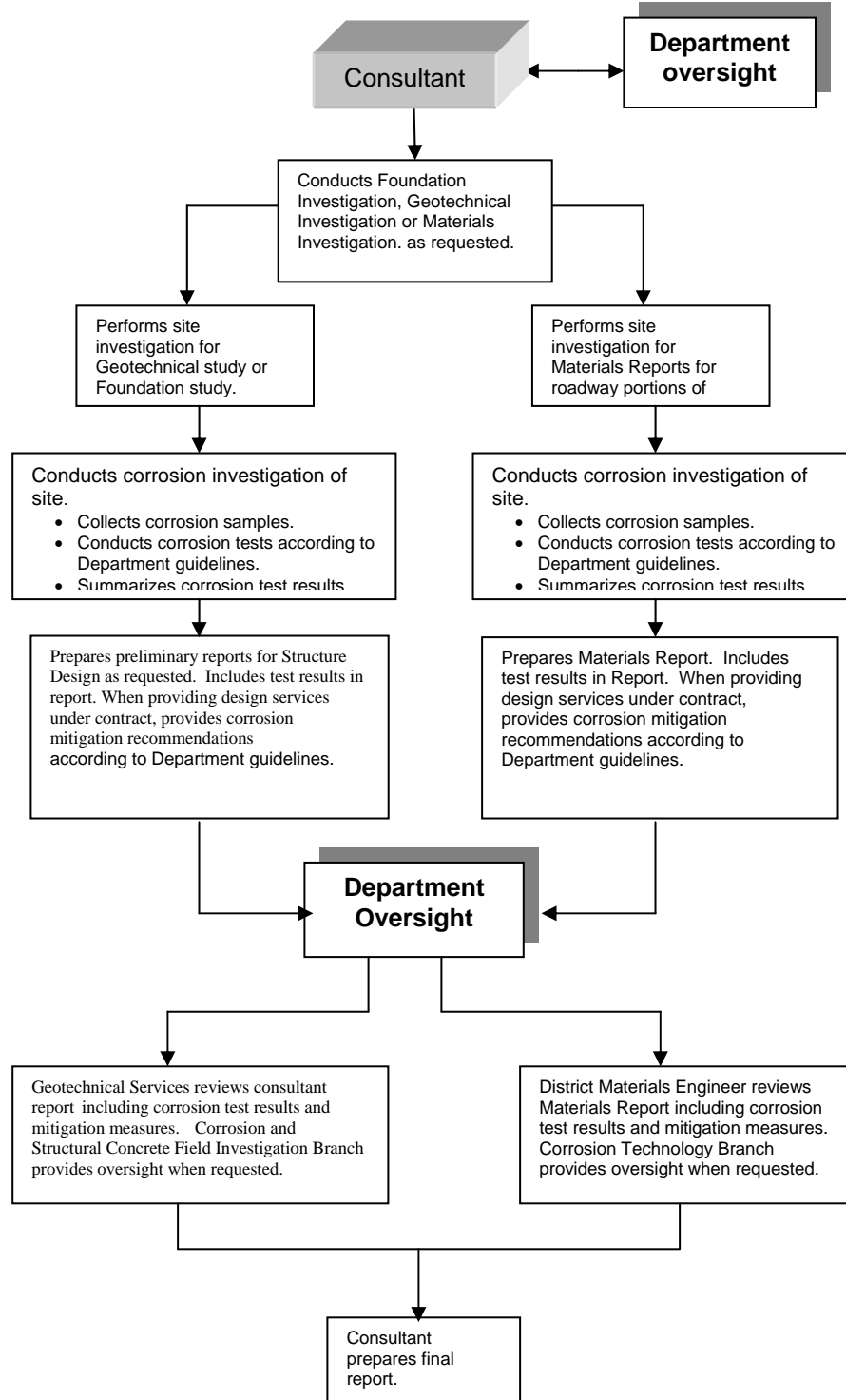
Corrosion testing of soil (both surface and subsurface soil samples) and water samples shall be performed in accordance with the applicable *California Test (CT)* (see References). If procedures and equipment other than those specified in the applicable *CT* are used, those variations must be approved, documented, and presented with the corrosion test results. References to the test methods used for corrosion testing must be included on each page that presents the corrosion test results and analysis. Some variations (like a one-point resistivity test instead of a minimum resistivity test) will not be allowed. If in doubt about whether alternative test methods are acceptable or not, contact the Corrosion and Structural Concrete Field Investigation Branch of METS before starting any testing.

Minimum resistivity and pH tests are outlined in *CT 643*. Test procedures for determining water-soluble sulfate and chloride contents are outlined in *CT 417* and *CT 422*. Consultants should follow the guidelines presented in this document for performing corrosion assessments of project sites when performing work for the Department.

The Corrosion and Structural Concrete Field Investigation Branch of METS is available to review all corrosion investigations conducted by consultants, should additional assistance be needed. Upon request from the functional groups performing oversight, the Corrosion and Structural Concrete Field Investigation Branch will comment on the corrosion aspects of Materials Reports, Geotechnical Design Reports, Foundation Reports, and Preliminary Reports prepared by consultants.



## Department/Consultants Interaction Flowchart







## **4. CORROSION BASICS**

Corrosion is the deterioration of a metal through a reaction with its environment. Typically, corrosion involves contact of the metal with moisture and air (oxygen). The deterioration that takes place during the corrosion process is the basic tendency of the metal to revert to its natural state prior to it being developed from its primary ore material. The most common example of corrosion is the rusting of steel into iron oxide, its primary ore as found in the earth.

The corrosion process of metals is an electrochemical process involving a transfer of electrons from the metal's surface to ions in the environment (the electrolyte).

Corrosion is often described in electrical terms as an electrical circuit consisting of four key components. These include an anode (where corrosion or chemical oxidation reactions are taking place), a cathode (where chemical reduction reactions are taking place), an electrolyte (solutions or conductive media providing the supply of chemicals needed to sustain the cathodic reactions at or near the metal surface), and a metallic path.

### **4.1 CORROSION TERMS**

The anode is where corrosion or chemical oxidation reactions are taking place. These are the locations on the metal surface where electrical current is being passed by chemical means from the metals surface to ions, elements or compounds in the electrolyte. The metal is losing electrons and combining with other elements in the environments by means of an oxidation reaction.

The cathode is where chemical reduction reactions are taking place. These are the locations on the metal surface where electrical current is being passed by chemical means from ions, elements or compounds in the electrolyte to the surface of the metal. This chemical reaction is a reduction reaction.

#### **ANODE**

An electrode where oxidation reactions (corrosion) occur.

#### **CATHODE**

An electrode where reduction occur.

The anode and cathode in a corrosion process may be on two different metals connected together forming a bimetallic couple, or as they may be on the same piece of metal. An area on a metal surface (or with two dissimilar metals, each respective metal) either becomes an anode or a cathode depending on the electrical potential of one area relative to the other. The electrical potential difference is the electromotive force of the cell and is the voltage difference between the anode and cathode of the cell. In any electrochemical cell, the area that is more negative in potential will undergo corrosion if coupled to the more positive area. The corrosion process is initiated by differences in the natural potential between the two dissimilar metals (bimetallic couple); metallurgical variations in the state

at different points on the surface a single metal; or localized variations in the environment such as variations in moisture content or oxygen concentration

The electrolyte is the material in contact with both the anode and the cathode that allows ions to migrate between the two electrodes. This allows ionic current flow to occur between the anode and the cathode. The electrolyte includes the source of atoms, elements, or compounds required for ionic current flow to and from the metal electrodes. The electrolyte is the environment that the metal is in contact with including whatever salts and liquids are present (e.g., soil for a buried metal or concrete for reinforcing steel).

The metallic path completes the electrical circuit and allows electrons to flow from the anode to the cathode in the electrochemical cell.

#### **ELECTROLYTE**

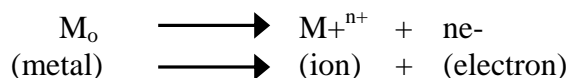
Soil and/or liquid or other conductive media adjacent to and in contact with the anode and the cathode that allows ions to migrate.

#### **METALLIC PATH**

Any conductor that allows electrons to flow.

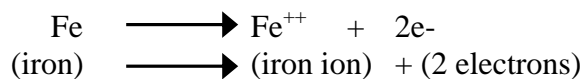
### **4.2 ELECTROCHEMICAL EQUATIONS**

The corrosion process can be described through a series of anodic and cathodic reaction equations (electrochemical equations) depending on the metal and ionic species involved. At the anode, iron is oxidized to the ferrous state, releasing electrons.

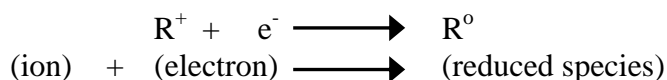


Where  $M_o$  represents a metal atom such as iron in a metallic structure; the arrow indicates the direction that reaction is occurring; the symbol  $M^{n+}$  represents a metal ion; and  $n^{+}$  along with  $ne^{-}$  indicates the number of electrons involved in the chemical reaction.

A common example is that of iron corrosion:

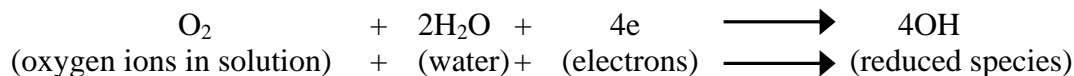
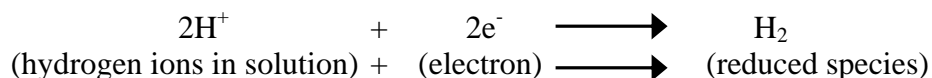


Iron gives up two electrons, which pass through the metal from an anodic site to a cathodic site where they are consumed in a cathodic (reduction) reaction. The cathodic reaction is in the form:



Where  $R^{+}$  represents a positive ion in solution,  $e^{-}$  indicates the number of electrons gained, the arrow indicates the direction that reaction is occurring; and  $R^0$  is the reduced atom produced as a result of the chemical reaction.

Two common examples of cathodic reactions are the reduction of hydrogen and oxygen:



#### 4.3 ELECTROMOTIVE FORCE SERIES AND GALVANIC SERIES

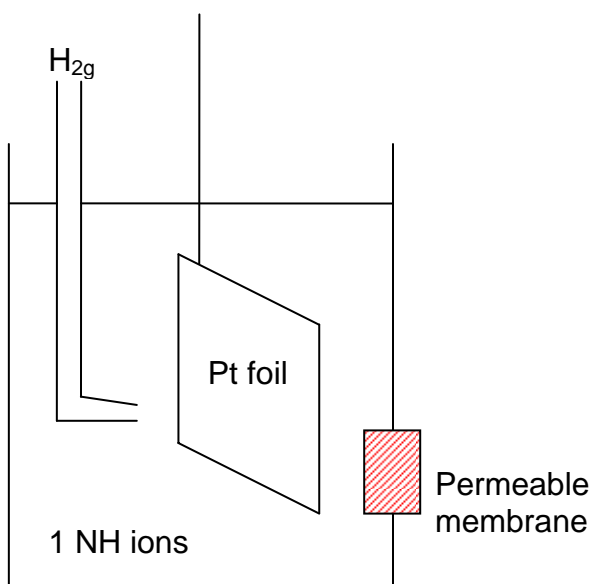
From the previous discussion, it can be seen that there is a transfer of electrons that occurs during the corrosion process. The example shown was that of steel in the presence of hydrogen and oxygen (both present as dissolved species in water). Similar electrochemical reactions can occur regardless of the conductive contact medium (soil, water, concrete, etc).

The standard that has been established to provide a reference scale of electrical potential values for metals and non-metals is known as the electromotive force (EMF) series or REDOX potential series.

To measure potentials (or voltages) for comparison of REDOX reactions, the reference used is a Standard Hydrogen Electrode (SHE). This electrode is constructed by bubbling gaseous hydrogen at 1 atmosphere of pressure over a piece of pure platinum in a solution of one normal  $\text{H}^+$  ions.

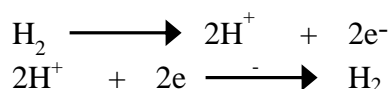
The redox reaction is therefore:  $2\text{H}^+ + 2\text{e}^- = \text{H}_{2\text{g}}$

Figure 1 shows a schematic of the SHE.



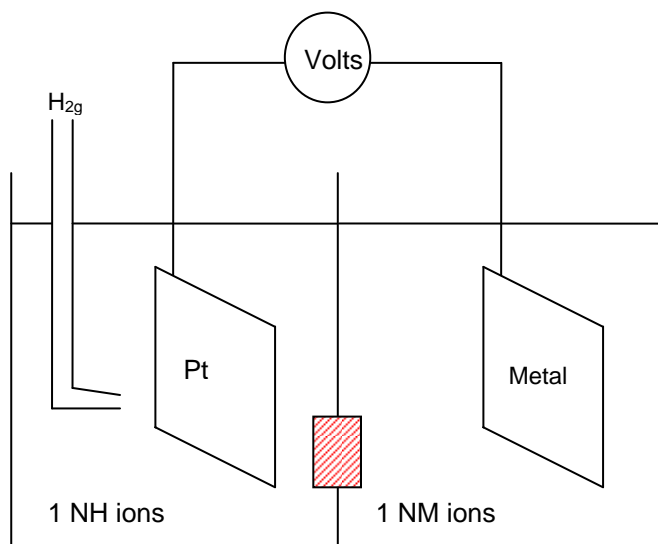
**Figure 1:** Schematic of standard hydrogen electrode (SHE). Hydrogen gas is bubbled into a beaker over platinum at a pressure of 1 atmosphere.

The potential for the SHE reaction by definition is 0.0 V. It is a complete REDOX reaction and will maintain a standard, constant voltage unless the standard conditions are deviated. The oxidation (anodic reaction) and the reduction (cathodic) reactions are given below:



Note that no electron removal is allowed and the hydrogen ion strength must be maintained.

Coupling different metals to the SHE allows their electrical potentials to be measured on a voltmeter using the SHE as a standard “zero” reference point. Figure 2 shows how a SHE is coupled to a metal using a high resistance voltmeter to measure the voltage of the metal. The high resistance of the voltmeter ensures that no current flows between the two REDOX cells and so no corrosion or deposition actually occurs. The REDOX reaction being measured must also be at standard condition. This series provides the *thermodynamic* probability that a pure metal under standard conditions will either ionize by an anodic reaction, or plate out in a cathodic reaction. Table 1 is a partial list of the established EMF series developed in a manner described using a SHE and various metals at standard conditions.



**Figure 2:** Cell for determination of EMF series or Redox potentials.

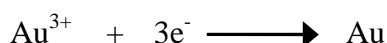
<b>Reaction</b>	<b>Potential at equilibrium (volts).</b>
$\text{Au} = \text{Au}^{3+} + 3\text{e}^-$	+1.498
$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- = 2\text{H}_2\text{O}$	+1.229
$\text{Pt} = \text{Pt}^{2+} + 2\text{e}^-$	+1.2
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- = 4(\text{OH}^-)$	+0.401
$2\text{H}^+ + 2\text{e}^- = \text{H}_2$	0.0
$\text{Fe} = \text{Fe}^{2+} + 2\text{e}^-$	-0.440
$\text{Cr} = \text{Cr}^{3+} + 3\text{e}^-$	-0.744
$\text{Zn} = \text{Zn}^{2+} + 2\text{e}^-$	-0.763
$\text{Al} = \text{Al}^{3+} + 3\text{e}^-$	-1.662

**Table 1:** Cell for determination of EMF series or Redox potentials.

The more negative the potential measured in the EMF series, the more likely the material is to oxidize in an anodic half cell reaction. Conversely, the more positive the potential in the series, the less likely the material is to oxidize. For example, gold (Au) is termed very noble as it has a high positive EMF value, while zinc (Zn) is very anodic as it has a relatively high negative value on the EMF scale. Connecting gold to zinc will induce an anodic reaction of the zinc to produce electrons:



Concurrently, the cathodic half-cell reaction will be favored in the half-cell with the more positive potential and gold ions will be reduced to gold by



The zinc will have corroded, as weight loss will occur. This process is essentially galvanic corrosion.

Another useful series is the galvanic series. The galvanic series is the electrical potential of a metal or alloy in a particular electrolytic solution (usually seawater). It is useful in determining how two or more metals will behave if electrically connected together in an ionically conductive environment. The electrical potential of each metal is measured as before against a standard. However, the standard may not always be the SHE. Other “reference electrodes” may be used. A reference electrode is simply an electrode (electrical conductor) that has a stable and well know electrical potential. The high stability of the electrode potential is usually reached by employing a redox system with constant (buffered or saturated) concentrations of each participant of the redox reactions. Examples of reference electrodes are the copper/copper sulfate ( $\text{Cu}/\text{CuSO}_4$ ) reference electrode, saturated calomel electrode (SCE) reference, and the silver/silver chloride ( $\text{Ag}/\text{AgCl}$ ) reference electrode.

An example of a galvanic series is shown in Table 2.

<b>Metal or Alloy</b>	<b>Potential in Volts (Versus Ag/AgCL Ref)</b>
Magnesium	-1.64
Aluminum Anode (Proprietary)	-1.53
Zinc (MIL-A-18001G)	-1.03
Cast Iron	-0.61
Carbon Steel (A1010)	-0.61
304 Stainless Steel (Active)	-0.53
Silver	-0.13
304 Stainless Steel (Passive)	-0.08
316 Stainless Steel (Passive)	-0.06
Graphite	+0.25
Platinum	+0.26

**Table 2:** Galvanic series in seawater versus a silver/silver chloride ( $\text{Ag}/\text{AgCl}$ ) reference cell.

In terms of corrosion, when looking at metals in an electrical potential series such as an electrical motive force series or a galvanic series, when two metals are coupled together, the more negative metal (the anodic metal) will corrode relative to the more cathodic (noble) metal.

## **5. PRINCIPLES OF CATHODIC PROTECTION**

Cathodic protection (CP) is an electrochemical technique used to control corrosion. CP provides a method to minimize deterioration of a metal (or structure) due to corrosion that is occurring as a result of contact with the surrounding environment (electrolyte).

Degradation is minimized by reversing the natural electrical current flow that is occurring during the corrosion process.

CP is achieved by connecting an external anode to the metal to be protected and allowing a direct current (DC) electric current to pass from that anode to the metal (the cathode) sufficient enough to keep all areas of the metal from corroding.

When electrical current can flow from the external anode in sufficient quantity to protect all areas of the metal simply by the natural difference in electrical potential between the anode and cathode, the cathodic protection system is referred to as a galvanic CP system. When an external DC power source is needed to increase the electrical current flow to the cathode to a level that sufficiently protects all areas of the metal in question, the system is called an impressed current CP system.

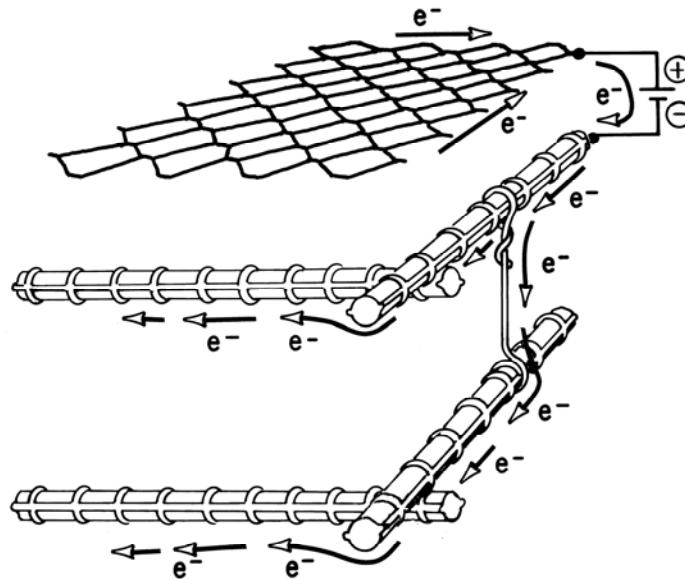
### **5.1 GALVANIC CP SYSTEMS**

Galvanic CP systems use reactive metals or alloys as anodes that are connected to the metal being protected. Active metals commonly used include zinc, aluminum, and magnesium alloys. Alloys may include combinations of these metals along with slight additions of minor elements to improve the alloys stability characteristics. With Galvanic CP systems, the sacrificial anode material is connected directly to the structure (metal) that requires corrosion protection. Coupling the two materials (the anode and the metal of the structure) will cause a shift in electrical potential of the structure metal since the structure metal is now the artificial “cathode” in the anode-cathode circuit and the bimetallic couple will try and reach an equilibrium potential. Contact to the reinforcement is made either by metallizing directly over the exposed reinforcement or by attaching a stud to the reinforcement when patching is needed for structural reasons. The zinc is then metallized over the exposed stud.

### **5.2 IMPRESSED CURRENT CP SYSTEMS**

Impressed current CP systems typically consist of a power source to drive the protective CP current, and an anode material that is relatively inert or that has a low dissolution rate. Impressed current CP systems are installed such that the anode does not directly contact the metal or structure being protected. The anode is connected to the positive side of the DC power supply, and the metal being protected is connected to the negative side of the power supply. The “circuit” is completed through the electrolytic path of soil or concrete that separates the anode and cathode. This resistive path is needed so that a direct electrical short circuit does not occur between the negative and positive leads of the power supply. Figure 3 shows a schematic of an impressed current CP system for reinforced

concrete. The battery symbol represents the DC power source. The positive side of the source is connected to a titanium anode mesh. The negative side of the source is connected to reinforcement in concrete. The concrete has been omitted from the view.



**Figure 3:** Schematic of an impressed current CP system for reinforced concrete. The battery symbol represents the DC power source. The positive side of the source is connected to a titanium anode mesh. The negative side of the source is connected to reinforcement in concrete. The concrete has been omitted from the view.

### 5.3 VECTOR GALVASHIELD XP ANODES

Caltrans Construction has made use of a galvanic CP products designed by Vector Corrosion Technologies for bridge expansions and repairs where new concrete is being placed in contact with older concrete. The product (Galvashield ® XP) acts as embedded galvanic anode and is comprised of zinc encased in a highly alkaline cementitious shell. Galvashield XP was developed to mitigate corrosion of reinforcing steel in concrete at the interface between new/repaired mortar/concrete and existing chloride contaminated concrete.

Historically, the area adjacent to patched concrete areas continues to experience accelerated corrosion due to the development of corrosion cells at the new to old concrete interface. Areas of concrete with residual chloride become anodic relative to the patched regions and corrosion of the steel around the patch circumference is accelerated. The Galvashield tied





directly to the steel near the interface of the old and new concrete provides passive cathodic protection since it is comprised of a sacrificial zinc core.

The anodes are tied directly to the reinforcing steel. The number of anodes are selected based on knowing the steel density ratio (surface area of steel/surface area of concrete) within the zone requiring protection, and recommended maximum spacing requirements for particular Galvashield products provided by Vector Corrosion Technologies.

Recommended spacing requirements are based on research indicating that a current density requirement between 0.05 and 0.2 microamps per cm<sup>2</sup> of steel surface area is needed to provide some corrosion protection benefit in concrete. Examples of design related calculations for selecting the number of anodes and anode spacing may be obtained from Vector Corrosion Technologies website at:

(<http://www.vector-corrosion.com/downloads.html>).

## **6. REQUIREMENTS FOR CONDUCTING CORROSION INVESTIGATIONS OF PROJECT SITES**

The Department has adopted the American Association of State Highway Transportation Officials (AASHTO) *Load and Resistance Factor Design (LRFD) Bridge Specification* requirement for a 75-year structure design life. However, culverts and drainage facilities typically require a 50-year maintenance free design life. Site specific corrosion investigations are needed to determine the corrosivity of a site and to provide appropriate corrosion mitigation measures to obtain the desired design lives. Factors that contribute to corrosion include the presence of soluble salts, soil and water resistivity, soil and water pH, and the presence of oxygen.

### **6.1 The Department's Definition of a Corrosive Environment**

Corrosion of metals is an electrochemical process involving oxidation (anodic) and reduction (cathodic) reactions on metal surfaces. For metals in soil or water, corrosion is typically a result of contact with soluble salts found in the soil or water. This process requires moisture to form solutions of the soluble salts. Factors that influence the rate and amount of corrosion include the amount of moisture, the conductivity of the solution (soil and/or water), the hydrogen activity of the solution (pH), and the oxygen concentration (aeration). Other factors such as soil organic content, soil porosity, and texture indirectly affect corrosion of metals in soil by affecting the factors listed above.

The Department defines a corrosive area in terms of the resistivity, pH, and soluble salt content of the soil and/or water. Since resistivity serves as an indicator parameter for the possible presence of soluble salts, it is **not included as a parameter** to define a corrosive area for **structures**. MSE walls (see Section 8 of these Guidelines) **include the resistivity as a parameter** to define a corrosive environment. In general, the higher the resistivity, the lower the rate for corrosion. A minimum resistivity value for soil and/or water less than 1000 ohm-cm indicates the presence of high quantities of soluble salts and a higher propensity for corrosion. Soil and water that have a minimum resistivity less than 1,000



ohm-cm are tested by the Chemical Testing Branch of METS for chlorides and sulfates. The Department uses the terms "corrosive" and "not corrosive" to describe the environment.

**For structural elements, the Department considers a site to be corrosive if one or more of the following conditions exist for the representative soil and/or water samples taken at the site:**

**Chloride concentration is 500 ppm or greater, sulfate concentration is 2000 ppm or greater, or the pH is 5.5 or less.**

For structural elements, appropriate corrosion mitigation measures for "corrosive" conditions are selected depending on the service environment, amount of aggressive ion salts (chloride or sulfate), pH level and the desired service life of the structure.

Chloride ions from saltwater, soil, or from de-icing salts can lead to corrosion of steel reinforcement in concrete and steel structures by breaking down the normally present protective layer of oxides (passive layer) present on the steel surface.

Similar to chlorides, sulfate ions may also lead to accelerated corrosion of steel reinforcement. In addition to causing metals to corrode, high amounts of sulfates are deleterious to concrete. Sulfates react with lime in the concrete to form expansive products that cause the concrete to soften and crack. Cracked concrete is more susceptible to attack by water and other aggressive ions that may accelerate the corrosion process. Sulfides in the soil can be an indicator of sulfate reducing bacteria which can lower the soil pH to more acidic, increasing the corrosion rates.

The presence of high acidity, pH of 5.5 or less, in soil or water is also considered a corrosive condition. Soil or water with a pH of 5.5 or less can react with the lime in concrete to form soluble reaction products that can easily leach out of the concrete. The result is a more porous, weaker concrete. Acidic conditions often cause discoloration of the concrete surface. A yellowish or rust color distributed over the concrete surface should be investigated.

## **6.2 Survey of Site Conditions**

In general, corrosion investigations, whether performed by Department staff or by consultants, should include a survey of the following site conditions:

- Extent of corrosive soils and water at the site.
- Presence of on-site fill material.
- A general description of the condition of any existing structures in the immediate vicinity that may impact the proposed structures. For example, do existing culverts



- show signs of corrosion or deterioration such as cracked concrete, exposed reinforcement, rust stains, failed coatings or excessive wear due to abrasion?
- Proximity of the structure or proposed structure to salt or brackish water.
  - Proximity of the structure or proposed structure to marine atmosphere.
  - Presence of abrasive water or high water flow (needed for scour consideration of structure foundations and abrasive water flows in culverts).
  - Proximity to natural features such as mineral springs or local geothermal activity.
  - Exposure of the structure or proposed structure to deicing salts (Climate Area III environments, where salt is applied to roadways and structures).
  - Presence of existing utilities such as light rail, or cathodic protection systems on pipelines, structures and underground storage tanks which may impose stray electrical current in the soil.

## **7. BRIDGE STRUCTURES**

As previously mentioned, factors that contribute to corrosion include the presence of soluble salts, soil and water resistivity, soil and water pH, and the presence of oxygen. Site specific corrosion investigations are needed to perform a complete assessment of corrosivity. See Section 6.1 of these Guidelines for a definition of a corrosive environment.

For rehabilitation and realignment projects, the Area Bridge Maintenance Engineers' (ABME) records as well as those maintained by the Corrosion and Structural Concrete Field Investigation Branch should be reviewed for information. This information is essential to identify appropriate mitigation measures.

For new alignments or when no maintenance records exist, a thorough review of all site investigations, sampling programs, and corrosion test results will be required to identify appropriate materials for potential corrosion mitigation.

### **7.1 Soil and Water Sampling for Foundation and Geotechnical Investigations for Bridge Structures**

Obtaining a **representative sample(s)** for testing may be one of the most important elements of any corrosion investigation. Representative sampling is defined here as obtaining samples of all materials encountered and ensuring that each sample is representative of all portions of each material. Representative sampling for corrosion testing should identify the worst case condition that exists in the materials to be encountered or used. Good sampling practices must be a primary consideration for all corrosion investigations.

Field sampling of soil and water for corrosion investigations shall conform to the requirements of *California Test (CT) 643 Method for Determining Field and Laboratory Resistivity and pH Measurements for Soil and Water*.



Sampling a site for corrosion assessment requires that samples of soil and water are obtained from both surface and subsurface material to ensure representation of all soil strata at the site within the limits of the proposed construction.

The following designated intervals shall be used for **corrosion sampling** during every structure foundation investigation conducted in the field. Generally, one boring with samples at the designated intervals should be sufficient unless there is a major change in the subsurface material within the proposed substructure area. The project Engineering Geologist or Engineer can make exceptions to the sampling guidelines. In some cases, the project geologist may feel that redundant sampling at the designed intervals is not necessary. The decision not to sample at the recommended intervals as described below for each boring shall be based on valid reasons. Those reasons should be noted in writing in the field logs and in the Foundation Report. For example, if a soil formation is present at multiple boring locations within the same structure site, it may not be necessary to obtain samples of the same formation from all borings.

- If fill material is present at the site, samples should be taken of the fill material as well as the native soil.
- One sample at near surface between 0.3 and 1.5 m (1 and 5 ft).
- One sample at the water table (if the water table is within the limits of the proposed pile foundation).
- Take an additional sample for each significant change in subsurface material to a depth of 1 m (3 ft) below the lowest anticipated ground water level (if the water table is within the limits of the proposed pile foundation).
- For concrete piles, take an additional sample for each significant change in subsurface material within the limits of the proposed pile foundation.
- Composite samples from more than one soil type or formation are not recommended.

Water samples should be obtained from surface water bodies at or near the structure site. This includes water from nearby bodies of water even though the structure may not come into direct contact with the water. For example, ***California Amendments (to the AASHTO LRFD Bridge Design Specifications - Fourth Edition)***

([http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/ca-to-aashto-lrfd-bds/page/sec\\_5\\_2011.pdf](http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/ca-to-aashto-lrfd-bds/page/sec_5_2011.pdf)), requires corrosion mitigation for reinforced concrete structures located within 300 m (1000 ft) of corrosive water (i.e., surface water with more than 500 ppm chlorides). Consequently, sampling of nearby water is particularly important at coastal locations or if the water body is subject to tidal influence. Use a clean wide-mouth beaker to collect the water sample. Swirl to rinse the beaker and pour out the contents to avoid contamination from the container. Fill the rinsed wide-mouth beaker a second time and retain the sample for laboratory testing. Pour off any film that is on the surface of the sample. One liter of water is sufficient for the laboratory to conduct resistivity, pH,



chloride, and sulfate testing. Transport the water sample in a sealed plastic container. The container used to transport the water should also be rinsed with the surface water to avoid contamination from the container.

Subsurface water samples are not normally taken during the drilling operation because of the difficulty in taking the sample. However, if there are wells present that permit sampling, water samples should be considered. Likewise, water samples for corrosion testing can be collected if a piezometer for groundwater measurements is installed. This is especially true when the local rainfall amounts routinely exceed 750 mm (30 in) rainfall per year. High rainfall amounts are generally indicators of acidic conditions that are aggressive to concrete and metal products. On the opposite end of the scale, low rainfall [less than 250 mm (10 in) per year] may account for large quantities of salts. Some of these salts may be aggressive to the structure under consideration, causing the structure to require mitigation.

If a well or piezometer is available for groundwater sampling, a narrow plastic sampling tube or bailer may be lowered into a clean, stabilized borehole. The sampler should be rinsed with the groundwater to avoid contamination from the container. After swirling and rinsing, lower the sampler a second time and retain the sample for laboratory testing. Pour off any film that is on the surface of the sample. One liter of water is sufficient for the laboratory to conduct resistivity, pH, chloride, and sulfate testing. Transport the water sample in a sealed plastic container. The container used to transport the water should also be rinsed with groundwater to avoid contamination from the container.

When imported material is used as structure backfill, the imported backfill should not be more corrosive than the native soil material. Consequently, the contract special provisions should specify corrosive parameters for the imported fill that are less corrosive than that of the native soil. The imported backfill should be tested in accordance with **CTs 643, 417, and 422** (see References) prior to placement. This criteria applies to imported soil and lightweight aggregate fill.

Representative samples from other sources (e.g. soils and/or aggregates) might include materials in windrows, stockpiles, borrow pits, conveyor belts, quarries, etc. The sampling technique used to sample these sources can have a significant effect on corrosion test results. Samples incorrectly taken from these sources may not be representative due to segregation of the coarse materials from the fine material. Procedures outlined in **CT 125, “Method of Test for Sampling Highway Materials and Products Used in the Roadway Structural Sections”** (see References), provide a guide to proper sampling techniques for these situations. While the title may not be directly related, the procedures are appropriate.

## **7.2 Bridge Structure Scour Assessment Related to Corrosion**

Scour can accelerate corrosion of steel piling. If scour is anticipated, the corrosion investigation shall include information such as anticipated scour depth and scour



frequency. For steel piling, additional metal thickness or protective coatings may be needed (see Section 10.1).

### **7.3 Reporting Corrosion Test Results for Bridge Structures**

For every soil and or water sample submitted to the Corrosion and Structural Concrete Field Investigation Branch, a Corrosion Test Summary Report is prepared and sent to the Engineer or contact submitting the sample for testing. These reports list the results of the corrosion tests conducted on the soil and/or water samples representative of each proposed structure site. This report also designates whether the site is corrosive or not corrosive based on the criteria established by these guidelines, and specifies the controlling (“worst case”) corrosion parameter test results that are used by the specification writers/designers to provide corrosion mitigation measures for each proposed structure. Geotechnical Services will generally summarize the corrosion test results for site samples in the Foundation Report or Geotechnical Design Report.

For situations where site-specific corrosion test data is not available, the Corrosion and Structural Concrete Field Investigation Branch may be contacted for additional assistance.

## **8. MSE STRUCTURES**

Most Mechanically Stabilized Embankment (MSE) structures are proprietary systems that require prior design and material use approvals. The list of pre-approved alternative Earth Retaining Systems is maintained by the Department ([http://www.dot.ca.gov/hq/esc/approved\\_products\\_list/](http://www.dot.ca.gov/hq/esc/approved_products_list/)). The DES Office of Structure Policy & Innovation (SPI) approves the design. The Corrosion and Structural Concrete Field Investigation Branch of METS reviews the corrosion aspects of newly proposed systems.

Most MSE structures are equipped with inspection elements that are either galvanized steel rods or straps, depending on the form of soil reinforcement (rod or strap) used in the actual MSE structure construction. Inspection elements are included in the initial construction of MSE structures so that they may be retrieved at a later date and assessed for corrosion and remaining structural capacity. Since the inspection elements are placed at various locations and levels in the wall, and since they are exposed to the same conditions as the actual MSE soil reinforcement, they may be used to provide an estimate of the overall condition of the MSE structure. Inspection elements are typically scheduled for retrieval at 5, 10, 20, 30, 40, and 50-year intervals.

### **8.1 Corrosion Requirements for MSE Structure Backfill**

The Department's *Standard Specifications Section 47-2.02 Structure Backfill* (see References), requires that the structure backfill material for an MSE structure meet the following corrosion related requirements:

- Minimum resistivity must be greater than 2000 ohm-cm, **CT 643**





- Chloride concentration must be less than 250 ppm, **CT 422**
- Sulfate concentration must be less than 500 ppm, **CT 417**
- pH must be between 5.5 and 10.0, **CT 643**

MSE backfill material that meets the above criteria will be considered not corrosive to both the metallic soil reinforcement as well as the reinforced concrete retaining wall. In addition to specifying not corrosive soil, the metallic soil reinforcement must be galvanized in accordance with the Department's standard galvanizing requirements **Standard Specifications Section 75-1.05** (see References).

## **8.2 Corrosion Sampling and Testing for MSE Structures**

For MSE structures, sampling of soil proposed for backfill material is required to establish that the material proposed meets the minimum requirements. Field sampling of soil and water for corrosion investigations shall conform to the requirements of **California Test (CT 643)**.

The contractor is responsible for using non-corrosive soil and water for MSE wall construction. When a source of backfill material (borrow site) is being proposed for use in constructing an MSE structure, the entire source area should be representatively sampled and tested to establish that all the material within the area to be used for structure backfill meets the minimum requirements. This may require taking many samples to properly describe the corrosivity of the proposed backfill material. If any of the material within a proposed borrow source does not meet the minimum requirements, those areas shall be clearly defined as "off limits".

In addition to "borrow-site" sampling performed by the contractor, the Department requires backfill sampling and testing during construction for quality assurance. **Bridge Construction Memo 145-8.0, Mechanically Stabilized Embankment Wall Construction Checklist, June 28, 2006,**

(<http://www.dot.ca.gov/hq/esc/construction/manuals/OSCCCompleteManuals/BCRPVol2.pdf>), advises the Structure Representative to obtain one 27-kg (60-lb) sample of backfill material for each level where inspection elements are installed. This amount of material is enough to conduct the corrosion tests (**CTs 643, 422, and 417**).

Water used for earthwork or dust control within 150 m (500 ft) of any portion of an MSE structure shall conform to the requirements for water that is used in conventionally reinforced concrete work (**Standard Specifications Section 47-2.03A and 90-1.02D**). This requires that the water have a maximum chloride concentration of 1,000 ppm, and a maximum sulfate concentration of 1,300 ppm.

## **8.3 Reporting Corrosion Test Results for MSE Structures**

Corrosion test results for backfill samples, submitted to the Corrosion and Structural Concrete Field Investigation Laboratory for testing, will be reported on a Corrosion Test Summary Report (see Section 5.3). Staff should keep in mind that although soil at a site



may be suitable for use around structure foundation elements, it may not be suitable for use as MSE structure backfill material.

## **9. SOIL AND ROCK ANCHOR SYSTEMS**

Soil and rock anchors typically consist of steel bar-type tendons or strand-type tendons and anchor assemblies that are grouted in cored or drilled holes. Soil or rock anchors are classified as Tieback Anchors, Tiedown Anchors, or Soil Nails. The following information is intended to give some brief background regarding these systems. Additional detailed information can be found in the Department's *Foundation Manual*, available at ([http://onramp.dot.ca.gov/hq/oscnet/sc\\_manuals/foundation/](http://onramp.dot.ca.gov/hq/oscnet/sc_manuals/foundation/)).

### **9.1 Tieback Anchors**

Tieback Anchors are used in both temporary and permanent structures. These types of anchors are typically associated with retaining walls and may contain either bar-type or strand-type tendons that are grouted into drilled holes of on-site foundation materials (either soil or rock). Corrosion mitigation measures for Tieback Anchors are specified in the contract special provisions [refer to *Bridge Reference Specifications 50-560 (50TIEB)* (see References)]. They include the use of PVC, HDPE or polypropylene sheathing, corrosion inhibiting grease and cementitious grout.

### **9.2 Tiedown Anchors**

Tiedown Anchors are typically foundation anchors for bridge footings that are grouted into cored, formed or drilled holes. They are used to provide additional restraint against rotation of the footings and can be installed in both soil and rock. Components of Tiedown Anchors are similar to those of Tieback Anchors. Corrosion mitigation measures for Tiedown Anchors are specified in the contract special provisions and *Bridge Reference Specifications 50-570* (see References). They include the use of PVC, HDPE or polypropylene sheathing, corrosion inhibiting grease and cementitious grout.

### **9.3 Soil Nails**

Soil nailing is a technique that is used to reinforce and strengthen an existing embankment. It is an effective technique used for large excavations. The basic concept is that soil is reinforced with closely spaced, grouted soil anchors or "nails" that are inserted (drilled) into the existing foundation material. Unlike Tieback and Tiedown Anchors, Soil Nails are not post-tensioned. They are forced into tension as the ground deforms laterally in response to the loss of support caused by continued excavation. Corrosion mitigation measures for Soil Nails are provided based on the corrosivity of the site, and are included in *Bridge Reference Specification 19-660 (19NAIL)*, (see References). Depending on the site conditions, corrosion mitigation measures may include sheathing with HDPE, epoxy-coated reinforcement and cementitious grout.

### **9.4 Rockfall Mitigation**

Rockfall protection facilities in corrosive environments (Section 4.1) should be protected against corrosion. There are many types of rockfall mitigation measures. There are two





types of systems involving wire and cable structures, referred to as static and dynamic systems. The static systems, referred to as drapery systems, lay on the slope. In this design, the rocks move slowly down slope into a ditch. There is assumed to be little damage to the wire or cable. Therefore, in corrosive environments the wire and cable are galvanized and plastic coated.

For dynamic systems in corrosive environments, since the wire and cable can be damaged by the rockfall, stainless steel should be specified for these components. Rockfall protection facilities should incorporate the following mitigation measures in corrosive environments. In accordance with the plans, special provisions, and type of system as explained above, wire mesh fabric, wire rope, and cable should be galvanized steel and coated with PVC or another approved material; or made of stainless steel. All anchors, bolts, nuts, washers, clamps, and similar exposed metal should be made of stainless steel. Care must be taken to ensure that the PVC or other coatings are not damaged during installation, especially at intersections with fasteners and clamps.

## **9.5 Gabions**

Section 72-16 Gabions of the *Standard Specifications* details the requirements for Gabions. For assistance regarding the corrosion evaluation and mitigation measures for gabions, refer to the 2001 *Gabion Mesh Corrosion* publication (<http://www.dot.ca.gov/hq/oppd/guidance.htm>).

## **10. CULVERTS**

### **10.1 Scope of Culvert Investigations**

The District Materials Branch (or the consultant under contract) is responsible for conducting a corrosion investigation for drainage facilities. This includes culverts to be repaired or replaced in addition to proposed new sites. For a rehabilitation project, it is common practice to perform a culvert survey of existing drainage facilities to determine the need for clean-out, repair, and/or replacement.

When a culvert has failed prematurely, sampling and testing of in-situ soil and water for selection of appropriate replacement culvert materials is suggested. Representative samples of both the soil and drainage water should be collected and tested. A culvert survey may also identify the need for new culverts where land use has changed drainage patterns. Maintenance personnel may be able to identify the latter more quickly.

### **10.2 Corrosion Sampling and Testing for Culverts**

Corrosion investigations for culverts should include sampling of in-situ soil within the limits of the existing or proposed culvert, sampling of water that will or does flow into the culvert, and sampling of any fill material used as backfill for the culvert. If a project will have multiple culverts, samples of soil and water should be obtained from each specific location on the project site. Ultrasonic testing of the wall thickness of steel pile can be measured at the request of the Corrosion and Structural Concrete Field Investigation Branch of METS.



For culverts, field-screening tests identified in *CT 643, Part 1 and Part 2*, “Method for Conducting Field Resistivity Survey and Sampling for Laboratory Tests” are used to identify the most aggressive on-site soil samples for corrosion testing. This simple screening test is highly recommended to identify the most aggressive soils at a site and can eliminate the need for obtaining multiple soil samples for lab tests. If suitable field-measuring equipment is not available to perform the screening tests, additional samples may be needed to obtain material that is representative of all material within the proposed limits of the culvert.

Representative surface water samples taken for proposed off-site drainage should be selected from the live stream or existing standing water at the inlet end of the facility. Surface water samples should also be collected from rivers, streams, wetlands, marshes, lakes, etc., if that water may come into contact with the structure (see Section 5.1). Water samples should never be taken when the water level is elevated due to recent storm runoff or flooding. Elevated stream flows dilute chemical concentrations in the stream making the sample concentrations appear lower than usual. Corrosion testing of soil samples (both surface and subsurface soil samples) and water samples shall follow the methods outlined in the *California Tests* (see References).

When imported material is used as structure backfill for metal products such as steel pipe culverts or reinforced concrete culverts and headwalls, the imported backfill should be less corrosive than the native soil material. Consequently, the contract special provisions should specify corrosive parameters for the imported fill that are less corrosive than those of the native soil. The imported backfill should be tested in accordance with *CTs 643, 417, and 422* prior to placement. This applies to imported soil and lightweight aggregate fill.

Slag based materials high in sulfate concentrations can attack the cement mortar in reinforced concrete pipe. If slag aggregate has been or is proposed for use as culvert backfill, it must be tested to determine its' suitability as structure backfill material.

### **10.3 Reporting Corrosion Test Results for Culverts**

It is the responsibility of the District Materials Engineer (DME) to prepare a Materials Report which includes the findings of the corrosion investigation and recommendations for allowable alternative culvert materials. It is important that the DME interprets the corrosion test data and provides the design engineer and specification writer with the best choices of alternative materials for the sites being investigated. These selected materials are then designated as the allowable alternative products on the Project Plans and in the Special Provisions for the project. Economics and hydraulics usually determine which alternative products are actually chosen by the contractor

The selection of alternative culvert materials should be in accordance with Chapter 850, “Physical Standards”, of the *Highway Design Manual (HDM)* - see References). Culvert material selection (including any coatings, linings, pavings, etc.) should provide corrosion



protection for a maintenance free service life. Maintenance-free service life is defined in **Topic 852 - Pipe Materials of the HDM** as 50 years (25 years in some cases).

Because there may be several responsible parties for various phases of a corrosion investigation, the results and recommendations may be found in different reports. The results may be contained in the Culvert Foundations section of the **2006 Geotechnical Design Reports** (see References). Additional detailed information to mitigate difficult corrosion problems may also be included in a separate memo or report prepared by the Corrosion and Structural Concrete Field Investigation Branch of METS. The design engineer needs to be aware of these sources and take the opportunity to review all the information during the design phase of a project. Corrosion Test Summary Reports prepared by the Corrosion and Structural Concrete Field Investigation Branch of METS will include results of all samples received for testing.

Corrosion investigations for either proposed or existing culverts should include the following subjects related to corrosion mitigation:

- A general description of the existing or proposed drainage facilities for both off-site and on-site drainage.
- The results of any culvert survey of existing drainage facilities in the immediate area.
- The presentation of all corrosion test results performed by the District lab, METS lab, and others. If testing has been performed by others, their report shall be included in the appendix.
- Identification of samples which are representative of the materials sampled and tested for each culvert site. Identification of the exact location of each sample.
- A statement regarding which materials were sampled and tested, including the sample location, depth, method of sampling (auger, backhoe, drill rig or shovel) and the classification of sampled material.
- Soil and water test results for minimum resistivity (ohm-cm), pH, sulfates (lb/yd<sup>3</sup> or ppm), and chlorides (lb/yd<sup>3</sup> or ppm).
- For corrosion test results of soil and/or water, include the recommended thickness/gage of (corrugated metal pipe) CMP for 50 years of service as specified in Chapter 850 of the HDM. Alternative bituminous-coated CMP should also be included. The Alternative Pipe Culvert Selection, **ALPIPE** software (see References) may be used to assist with selecting gage thickness.
- For RCP and box culverts, include the recommended clear concrete cover over the reinforcing steel and concrete mix design for 50 years of service as specified in Chapter 850 of the HDM.
- Include all recommended allowable alternative culvert materials and their thickness for either 25 or 50 years of maintenance-free service according to the provisions of the Chapter 850 of the HDM. These recommended materials should also be readily available from vendors.



- Include, if appropriate, any mitigation measures necessary for stray current problems. The DES Office of Electrical, Mechanical, Water, and Wastewater Engineering should be contacted for assistance in mitigating stray current corrosion. See Section 12 of these guidelines for additional information regarding stray current.
- Also include any specific recommendations that may be pertinent to the project or helpful to the designer, specification writer, or construction personnel due to unusual circumstances.

The results of a culvert survey along with the corrosion test results of soil and water collected from the site will provide the District Materials Engineer (DME) with complete information to make alternative material selections. If the service life of existing culverts are known, then the performance history of existing culverts would generally be more reliable than the results of laboratory tests since the performance history is based on the culvert's exposure to corrosion, bed load, and abrasion. For example, soil and water corrosion test results may suggest that uncoated galvanized steel culverts may be appropriate for a particular site. However, if the existing culverts are uncoated galvanized steel but have corroded prematurely, it is obvious that a different material should be used for any new culverts. In other words, the failed performance history of the existing culverts would override the results of the corrosion test results. All elements that affect the life of the culvert must be addressed if the culvert is expected to perform as intended.

#### **10.4 Alternative Culvert Materials**

As noted in the previous section, the software, *ALPIPE*, is available for selecting alternative culvert materials based on site conditions.

##### **Galvanized Steel Pipe**

The selection of galvanized steel pipe is based on the corrosion test results from *California Test 643* (both soil and water testing) and the criteria presented in Chapter 850 of the *HDM*. The years to first perforation and the maintenance-free service life is based solely on the minimum resistivity and pH of the soil and/or water samples as shown in Figures 855.3A (Minimum Thickness of Metal Pipe for 50 Year maintenance-Free Service Life) and 855.3B (Chart for Estimating Years of Perforation of Steel Culverts), Chapter 850 of the *HDM*.

In corrosive environments, protective coatings, linings, and pavings on the inside and/or outside of steel pipe and culverts can be used to extend the maintenance-free service life. Chapter 850 of the *HDM* and *Section 66-1.02C Protective Coatings, Linings, and Pavings of the Standard Specifications* (see References) describes the various types of coatings and linings that may be selected to extend the maintenance-free service life.

Any damage to galvanizing, protective coatings, linings, and pavings that occurs during handling, installation, or construction must be rejected or repaired as specified in



accordance with manufacturer's recommendations. Damage includes scratches, pinholes, cracks, or coating de-bonding.

### **Aluminum and Aluminized Steel (Type 2) Pipe**

Aluminum is an alternative material allowed when corrosion test results and abrasive conditions meet the criteria in Chapter 850 (*Topic 855 - Design Service Life*) of the *HDM*. Aluminum culverts include corrugated aluminum pipe and pipe arches, aluminum spiral rib pipe, and structural aluminum plate pipe and arches. For a 50-year maintenance-free service life, aluminum can only be used if the pH of the soil, backfill, and drainage water is within the range of 5.5 to 8.5 (*Section 855.3 Corrosion*). In addition, the minimum resistivity of the soil, backfill, and drainage water must be 1,500 ohm-cm or greater.

As an alternative to coating steel pipe with zinc (i.e., hot-dip galvanizing), steel pipe can be aluminized (Type 2). Aluminized steel pipe is steel pipe that is protected against corrosion by hot-dipping in an aluminum coating. The Department allows the use of 1.6 mm (16 gage) thick (minimum) aluminized steel (Type 2) pipe for pH values between 5.5 and 8.5 and minimum resistivity's in excess of 1,500 ohm-cm. Greater wall thickness would be considered for increased structural needs, but is not needed for corrosion resistance. Bituminous or polymerized coatings are not recommended for corrosion protection of aluminized steel, but may be used for abrasion resistance.

### **Non-reinforced Concrete Pipe**

The use of non-reinforced concrete pipe can be advantageous when reinforcing steel is not required to provide strength. Without reinforcing steel, the presence of chloride and stray current cannot compromise the service performance of the pipe. Acidity and sulfates in the soil and/or water, however, can affect this type of pipe by attacking the cement.

Table 855.4A (Guide for the Protection of Cast-In-Place and Precast Reinforced and Unreinforced concrete Structures Against Acid and Sulfate Exposure Conditions) in Chapter 850 of the *HDM* provides mitigation measures to protect against corrosion due to acids or sulfates. The corrosion mitigation measures improve the concrete mix design by using mineral admixtures, reduced water content, increased supplementary cementitious material content, and Type V cement.

### **Reinforced Concrete Pipe**

Reinforced concrete pipe (RCP) is typically precast, performs well under most conditions, and is commonly selected when a corrosive environment exceeds the limits for using corrugated metal pipe. The initiation of corrosion is delayed in RCP due to the concrete cover over the reinforcing steel. When the chloride concentration at the site reaches 500 ppm in either the soil, or drainage water, mitigation is necessary to protect against chlorides from causing corrosion of the reinforcing steel. If chlorides penetrate the concrete and cause the reinforcing steel to corrode, the concrete will eventually crack, spall, and may fail. *Section 65-2.02 Materials* of the *Standard Specifications*, *Topic 855 - Design*



*Service Life* in Chapter 850 of the **HDM** and Section 10.2 of these Guidelines provide corrosion mitigation measures to protect against corrosive environments.

#### **Reinforced Concrete Box Culverts and Arch Culverts**

Corrosion protection for reinforced concrete box culverts and arches may be achieved for reinforced concrete structures as specified in **Section 51-4.03E Box Culverts** of the **Standard Specifications**. Section 10.2 of these Guidelines provides corrosion mitigation measures to protect against corrosive environments.

#### **Plastic Pipe**

Plastic pipe is not subject to corrosion and can be a good performer in areas that are corrosive. In general, exposure to sunlight (ultraviolet rays) has an adverse effect on the service life of plastic pipes and products. For a plastic pipe, ultraviolet (UV) rays from the sun can induce degradation and ultimately cause loss of mechanical properties, which may result in premature failure of the pipe. HDPE and PVC plastic pipes approved for use by the Department have UV inhibitors added for protection against sunlight.

When plastic pipe is installed in areas that may be subject to fire, consider using concrete headwalls or metal flared end sections to reduce the potential damage to the ends of the pipe. Also, accumulated debris and trash may carry a fire into the pipe.

### **10.5 Cement Slurry, Controlled Low Strength Material (CLSM) or Concrete Backfill for Culverts**

When cement slurry, controlled low strength material (CLSM) or concrete is used as structure backfill for pipe culverts, selected pipe culvert material shall conform to the requirements of **Chapter 850** of the **Highway Design Manual** for the in-situ soil and water. Corrosion testing shall be conducted in conformance with the requirements of **California Tests 643, 422 and 417**.

When placing culverts in existing roadways, it is sometimes necessary to use fast setting concrete backfill. Anytime an admixture is used to accelerate the set time of concrete that has metal products within the concrete or slurry, only non-chloride admixtures should be considered (i.e., admixtures containing calcium chloride may not be used).





## **11. CORROSION AND STRUCTURAL CONCRETE FIELD INVESTIGATION LAB SERVICES**

### **11.1 Testing Services**

The Corrosion and Structural Concrete Field Investigation Branch (CSCFI) provides various laboratory testing services for the Department's functional units. These services include salt spray exposure testing [in accordance with *American Society of Testing Materials (ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus)*] of materials (fencing, coatings, corrosion inhibiting grease, new products, etc.); corrosion testing of soil and water for minimum resistivity, pH, and water soluble sulfates and chlorides (*CTs 643, 417, and 422*, respectively); and testing of total chloride concentrations of concrete cores (*CT 404*). Other specialty tests and field investigations are performed when appropriate (see Section 11.2 of this Guideline).

The Department's District or regional labs conduct their own minimum resistivity and pH tests for soil and water for culvert investigations. Since these labs do not have the capability to run chloride and sulfate tests, soil and water samples having minimum resistivity results of less than 1000 ohm-cm are sent to METS for these tests. These labs must include their resistivity and pH results when submitting samples for chlorides and sulfates.

A corrosion testing flowchart is included (along with mailing addresses for labs) at the end of Section 9. The roles and responsibilities regarding corrosion testing for soil and water samples received from Geotechnical Services, District Materials Labs, Construction Labs, or others is shown in the flowchart.

The Geotechnical Lab logs in the soil samples and reviews TL-0101 forms for completeness before sending them to the Grade Bench for sample preparation, including drying, screening, and splitting of material for requested testing. After preparing the samples, the Grade Bench distributes them to the CSCFI Lab for corrosion testing, and to other units depending on the requested tests.

### **11.2 TL-0101 Form**

Department staff requesting corrosion testing should use the TL-0101 form. The TL-0101 form or Sample Identification Card should be completed with all available information entered. Include the name, fax number, and telephone number of the person/s responsible for sampling and the name and **complete** mailing address of the contact/s to receive the test results. Attach the TL-0101 form to the sample. If necessary, additional information may be included in an attached memo.

It is not required to fill out individual TL-0101 forms for each sample if samples are from the same boring, however, copies of original forms must be legible. Please label each sample with the TL 101 Sample Identification Card Number and a borehole number and depth when applicable. Please clearly state whether the sample is to be used as backfill for an MSE wall.



### **11.3 Corrosion and Structural Concrete Field Investigation Lab's Test Results Database**

The Corrosion and Structural Concrete Field Investigation Branch of METS maintains a computer database of all laboratory corrosion test results for the tests it conducts on soils, water and concrete along with the results reported to the branch by the district labs. This allows the Corrosion and Structural Concrete Field Investigation Branch to provide the Districts and others with quick and easy retrieval of historical testing records for use in planning, contract litigation, etc. Records can be searched by district, county, route and bridge number, etc.

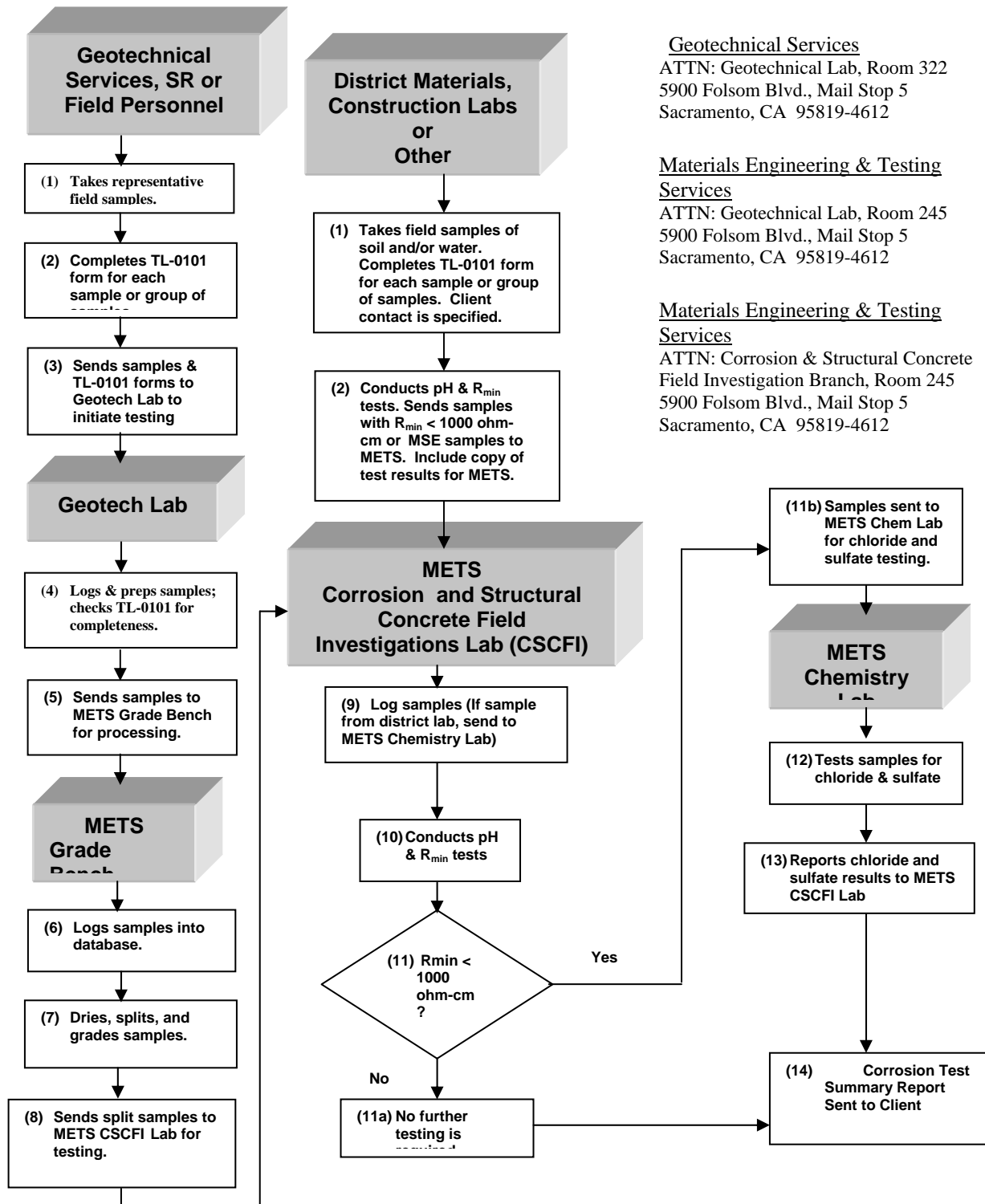
After a sample has been tested, the information is entered into the Corrosion and Structural Concrete Field Investigation Branch database and a formatted summary sheet of all test data is created. A Corrosion Test Summary Report (PDF format) will be emailed to the contact listed on the TL-0101. The report summarizes test results for all samples received for a particular project site, whether or not the site is corrosive, and specifies the most corrosive parameters (worst case scenario) from all samples received for the site.

Unused portions of sampled material will be kept in the Corrosion Lab for approximately 90 days after the test results are reported. After 90 days, the materials will be discarded. If needed, arrangements can be made to return the unused portions after testing. Requests to return the unused sample material should be made at the time of the requested services for corrosion testing.





## Corrosion Testing Flowchart for Soil and Water Samples



### Geotechnical Services

ATTN: Geotechnical Lab, Room 322  
5900 Folsom Blvd., Mail Stop 5  
Sacramento, CA 95819-4612

### Materials Engineering & Testing Services

ATTN: Geotechnical Lab, Room 245  
5900 Folsom Blvd., Mail Stop 5  
Sacramento, CA 95819-4612

### Materials Engineering & Testing Services

ATTN: Corrosion & Structural Concrete  
Field Investigation Branch, Room 245  
5900 Folsom Blvd., Mail Stop 5  
Sacramento, CA 95819-4612



## **12. CORROSION MITIGATION MEASURES**

The following section provides some useful information regarding corrosion mitigation measures for structural elements. As previously mentioned, Department guidelines such as the *Bridge Design Specifications*, *Memos to Designers*, *Standard Specifications*, *Special Provisions*, *Bridge Design Reference Specifications*, and the *Highway Design Manual* have been developed to cover these topics. The purpose of the information provided in this section is to provide additional background information regarding corrosion mitigation in addition to the listed Department guidelines.

### **12.1 Corrosion Mitigation Measures for Steel Piles**

The corrosion rate of steel piles in soil is influenced by a number of corrosion related parameters. These include soil minimum resistivity, pH, chloride content, sulfate content, sulfide ion content, soil moisture, and oxygen content within the soil. Measurement of these parameters can give an indication of the corrosivity of a soil. Unfortunately, because of the number of factors involved and the complex nature of their interaction, actual corrosion rates of driven steel piles cannot be determined by measuring these parameters. Instead, an estimate of the potential for corrosion can be made by comparing site conditions and soil corrosion parameters at a proposed site with historical information at similar sites.

In general, the corrosion behavior of structural steel in soil can be divided into two categories, corrosion in disturbed soil and corrosion in undisturbed soil. A disturbed soil is a soil in which digging, backfilling, or other soil upheaval has taken place. Driven steel piles generally have the majority of their length in undisturbed soil. However, excavation and backfilling for footings and pile caps create a region of disturbed soil near the top of the piles, increasing the availability of oxygen and the probability of corrosion.

A major contributor to increased corrosion rates of driven steel piles in soil is the availability of oxygen. In general, oxygen content is greater near the upper portion of the pile, greater in disturbed soils, and greater in soil near a ground water surface. Soil disturbance in the upper region of the pile may create areas of differential aeration within and just below the disturbed soil zone. This may lead to increased pitting corrosion of the steel piles within or near the disturbed zone.

Local corrosion cells may exist in some miscellaneous fills that can lead to increased corrosion rates of driven steel piles. These miscellaneous fills include combinations of natural soils (clays and sands), construction debris, ash and cinder material, as well as waste inorganic materials. Increased corrosion rates have been documented in these fills where soil pH was low, 5.5 or less, and soil minimum resistivity was below 1,000 ohm-cm. For these reasons, it is always recommended to test fill material for corrosivity.

When steel piles are used in corrosive soil or corrosive water, special corrosion protection considerations for the steel may be needed. The extent of corrosion protection for steel piles will depend on the subsurface geology, the location of the groundwater table, and the

depth to which the soil has been disturbed. Corrosion protection mitigation may include the need for sacrificial metal (corrosion allowance) or the use of protective coatings and/or cathodic protection.

Steel piling may be used in corrosive soil and water environments provided that adequate corrosion mitigation measures are specified. The Department typically includes a corrosion allowance (sacrificial metal loss) for steel pile foundations. Sacrificial metal or corrosion allowance is the thickness of metal (above what is structurally required for the pile) needed to compensate for the loss of metal that will occur as the pile corrodes. This extra metal thickness is added to all surfaces of the pile exposed to the corrosive soil or water.

The Department currently uses the following corrosion rates for steel piling exposed to corrosive soil and/or water.

<b>Soil Embedded Zone</b>	<b>0.025 mm (0.001 in) per year</b>
<b>Immersed Zone</b>	<b>0.100 mm (0.004 in) per year</b>
<b>Scour Zone</b>	<b>0.125 mm (0.005 in) per year</b>

The corrosion rates apply only if the soil and/or water are corrosive. If a site is characterized as not corrosive, then no corrosion allowance (sacrificial metal loss) is necessary. This information is also included in *Bridge Memo to Designers 3-1*, (see References).

For steel piling driven into undisturbed soil, the region of greatest concern for corrosion is the portion of the pile from the bottom of the pile cap or footing down to 1 m (3 ft) below the water table. This region of undisturbed soil typically has a replenishable source of oxygen needed to sustain corrosion. A corrosion rate of 0.025 mm (.00098 in) per year should be used for the length of pile in this region. No corrosion rate is required for the length of pile outside of this region.

The corrosion rates listed above should be doubled for steel H-piling since there are two surfaces on either side of the web and flanges that are exposed to the corrosive soil and/or water. For example, the length of a steel H-pile that is immersed in corrosive water and has a 75-year design life should have a corrosion allowance of 15 mm (0.6 in), calculated using 0.1 mm/yr (0.004 in/yr) x 75 years x 2 exposure faces.

For steel pipe piling, used in corrosive soil and/or water, the corrosion allowance is only needed for the exterior surface of the pile. The interior surface of the pile (soil plug side) will not be exposed to sufficient oxygen to support significant corrosion.

The above corrosion rates and allowances for piles are also applicable to permanent steel shells, used at corrosive sites that are intended to carry axial or lateral structural load.



However, steel casings do not need a corrosion allowance when they are used only for constructability, and are not intended to carry axial or lateral structural load.

The use of coatings on driven steel piles may be considered as an alternative corrosion protection strategy. Before this alternative is selected, however, the need to protect the coating from damage during the driving operation, coating repair strategies, and the method of field coating pile splice sections should be considered. Contact the Corrosion and Structural Concrete Field Investigation Branch of METS for assistance with selecting coating alternatives.

When coatings are proposed to mitigate corrosion of steel piles, the effect of the coating on the skin friction capacity of the pile should also be considered. Contact the DES Geotechnical Services for assistance with concerns related to reduced skin friction capacities of piles.

## **12.2 Corrosion Mitigation Measures for Reinforced Concrete**

Uncontaminated, high quality concrete normally provides excellent corrosion protection for reinforcing steel. The high pH environment, greater than 12.5, of the concrete keeps the reinforcing steel in a non-active corrosion state. Intrusion of chlorides into the concrete through contact with chloride-contaminated soil, water or marine atmosphere, however, may lead to corrosion of the embedded reinforcing steel.

Contact of the concrete with soil or water containing sulfates can, over time, cause deterioration, increased porosity, and decreased pH of the concrete. In addition to the obvious loss of integrity of the concrete, this degradation may also lead to accelerated corrosion of the reinforcing steel.

Corrosion protection of reinforced concrete is required in accordance with Section 5 *Concrete Structures* of *California Amendments (to the AASHTO LRFD Bridge Design Specifications - Fourth Edition)* (see References). *Table 5.12.3-1 Minimum Concrete Cover (inches) for 75-year Design Life* specifies the use of increased clear concrete cover over the reinforcing steel, corrosion resistant concrete mix designs, and epoxy coated reinforcing steel for corrosion protection of reinforced concrete exposed to chloride environments. This document also provides mitigation measures to protect against corrosion due to acids or sulfates.

*Section 90-1.02H Concrete in Corrosive Environments* of the *Standard Specifications* provides specification language for corrosion resistant concrete mix designs that address corrosive conditions specified in Section 5 *Concrete Structures* above.

Concrete mixes used by the Department to mitigate chlorides are based on the diffusion rate of chlorides using Fick's Second Law of Diffusion. Dense concrete mixes that are less permeable slow the diffusion of chlorides through concrete. Therefore, the time for chlorides in the soil or water to reach the reinforcing steel is increased. It is desirable to



slow the rate of chloride diffusion in reinforced concrete because high chloride contents at the level of the reinforcing steel will cause the reinforcing steel to corrode.

The use of supplementary cementitious materials (such as flyash, silica fume, metakaolin, etc.), reduced water content, and increased cementitious material content result in high-density, durable concrete. Additional thickness of clear cover over the reinforcing steel also increases the time it takes for chlorides to reach the level of the reinforcement. **Bridge Memo to Designers 10-5** (see References) provides additional guidance regarding protection against corrosion for reinforced concrete due to chlorides, sulfates, and acids.

In addition to low permeability concrete and increased cover to delay the initiation of corrosion, the Department also specifies epoxy-coated reinforcing steel (ECR) for reinforced concrete subjected to high concentrations of deicing salt (Climate Area III) and salt or ocean water.

Protective coatings for reinforced concrete surfaces, such as dampproofing and waterproofing may also be used as mitigation measures. See Section 10.4 of these guidelines for additional information regarding these treatments.

### **12.3 Epoxy-coated Reinforcing Steel**

The Department's *Standard Specifications Section 52-2 Epoxy-Coated Reinforcement and Epoxy-Coated Prefabricated Reinforcement* currently has specifications for two types of epoxy-coated reinforcing steel (ECR): Pre-fabricated ECR (purple or gray in color) and post-fabricated ECR (green in color).

Pre-fabricated ECR is specified for reinforced concrete that is in direct contact with water containing 500 ppm or more of chlorides, or in the marine splash zone. It is generally not used if only the soil is corrosive. For this type of coating, the reinforcing steel is cut to size and bent to shape (i.e., pre-fabricated) prior to being coated with a protective fusion bonded epoxy coating. Pre-fabricated ECR is not intended to be bent or re-bent after being coated. Epoxy powder formulations meeting the requirements of specified in Section 52-2 are "less-flexible", highly cross-linked coatings that contain special organic fillers which greatly enhance their resistance to water penetration, lower their susceptibility to loss of coating adhesion and under film corrosion, and provide greater resistance to ultraviolet (UV) radiation. These formulations are better suited to protect reinforcing steel in concrete placed in continuously wet marine environments when compared to post-fabricated epoxy powder formulations. **Bridge Memo-To-Designers 10-6 Use of Pre-Fabricated Epoxy Coated Reinforcement in Marine Environment** (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%2010/10-6.pdf>) provides additional guidance regarding the use of epoxy-coated reinforcement.

Post-fabricated (green) ECR formulations meet the requirements of Section 52-2 of the Department's *Standard Specifications* (see References). For this type of ECR, straight bars



or wire are coated and subsequently cut and bent to shape. Post-fabricated ECR is generally used in Climate Area III where deicing salts are used.

#### **12.4 Dampproofing and Waterproofing**

When a coating is required to minimize exposure of concrete, reinforced concrete, or metal surfaces to moisture, dampproofing or waterproofing should be considered. ***Standard Specification 54 Waterproofing*** describes both methods in detail (see References).

Dampproofing and waterproofing may be considered for a concrete surface or for a column retrofit when a steel shell is used. Generally, corrosion can occur where the soil is in contact with the surface to be protected; therefore, it may only be necessary to treat those surfaces in contact with soil. Dampproofing and waterproofing may also be considered for protecting concrete surfaces exposed to highly acidic soil and/or water. These treatments may also be used as mitigation measures to protect RCP from stray current by coating the inside and outside of the pipe.

Dampproofing requires the concrete surface to be cleaned and coated with a primer, then mopped with two coats of waterproofing asphalt. Waterproofing is similar to dampproofing, but provides even more corrosion protection. In addition to cleaning and treating with a primer, two layers of saturated glass fabric membrane and three mop applications of waterproofing asphalt are required for concrete structures.

Because of air quality restrictions in some geographical regions, ASTM Designated material D-41, a solvent-based primer, may not be allowed. When the ASTM D-41 primer cannot be used, slow curing emulsion alternatives SS1H or CSS1H, specified in Section 94 of the ***Standard Specifications***, may be used (verify Volatile Organic Content (VOC) with the local air quality management board).

### **13. EXISTING STRUCTURES**

#### **13.1 Cast-In-Drilled-Hole (CIDH) Pile Anomalies**

CIDH piles with anomalies may need to be repaired, supplemented, or replaced depending on the extent of anomalies within the CIDH pile. ***Memo to Designers 3-7 Design Data Documentation and Evaluation of Anomalous Concrete Shafts*** (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%203/mtd-3-7.pdf>) provides information regarding the acceptance, rejection, and mitigation requirements for CIDH piles. The Corrosion and Structural Concrete Field Investigation Branch reviews anomalies indicated on the Pile Design Data Forms (distributed by the Foundation Testing Branch) for corrosion potential.

Consideration of corrosion potential is only needed for anomalies that are between the top of the pile and 1 m (3 ft) below the lowest possible ground water surface. For anomalies outside these limits, and where no stray current source is identified, no consideration of corrosion potential is required. The rationale for this requirement (excluding the issue of possible corrosion from outside electrical sources) is that sufficient oxygen is not available





below the ground water surface to promote significant corrosion of nearly exposed or exposed steel (such as reinforcement at or near a pile anomaly).

### **13.2 Field Investigation Team (FIT)**

Rehabilitation of structures is the responsibility of the Office of Structure Maintenance and Investigations (SMI) (<http://smi.dot.ca.gov/>). Area Bridge Maintenance Engineers (ABME's) perform routine structure inspections every 2 years to document the ongoing condition of structures. This information can be viewed in the Bridge Inspection Records Information System (BIRIS). In-Depth inspections are conducted by the ABME on damaged structures, structures that have developed specific problems, structures suspected of developing problems, or structures requiring special analysis such as scour evaluations. The scope of these investigations are typically sufficient to determine the need for emergency load restrictions or closure of the structure, potential for scour, monitor a changing condition, and to assess the level of effort necessary to perform a repair. Materials investigations are often required to provide an accurate assessment of a structure and structure site during an In-Depth Inspection. The Office of Structural Materials (OSM) provides support to SM&I during Structural Concrete Materials Investigations.

Structural Concrete Materials Investigations may be requested by an ABME during their (In-Depth) inspections on an as-needed basis. These investigations are coordinated by the SMR (Structure Material Representative) local to the ABME's region. SMR's assist ABME's with structure investigations where field sampling is required and/or complex non-destructive testing (NDT) testing is needed. Field site conditions are reviewed, samples are retrieved and tested, and data is analyzed to assess structure degradation mechanisms and to determine the types of rehabilitation methods that should be employed to extend the service life of a structure or to determine if replacement is needed.

SMR's coordinate field and lab testing activities with OSM's Corrosion and Structural Concrete Field Investigation Branch (CSCFI). FIT has been established in the Branch to provide support to SMR's during field evaluation stages of structure investigations. Specialized equipment and sampling methods are available to assist the SMR with their Structural Concrete Materials Investigation. The responsibilities of the SMR and Field Investigation Team are specified in the OSM's Practices and Procedures Manual (OSMPP) ([http://onramp.dot.ca.gov/hq/esc/mets/structure\\_materials/documents/OSMPP.pdf](http://onramp.dot.ca.gov/hq/esc/mets/structure_materials/documents/OSMPP.pdf)).

Processing concrete for corrosion testing typically involves coring the structure and in the lab, cutting the core into 25 mm (1.0 in) segments, crushing the segments, and pulverizing each segment as a separate sample so that it will pass a 150  $\mu\text{m}$  (No. 100) size sieve. Chemical analyses for chlorides, in accordance with *California Test 404*, and if suspected, chemical analysis for sulfates *California Test 417* (see References), are then performed on the minus 150  $\mu\text{m}$  material. Test results for chloride and sulfate are calculated in ppm or the equivalent  $\text{kg/m}^3$  ( $\text{lbs/yd}^3$ ) of concrete. The CSCFI Branch reports the chloride and sulfate (if applicable) test results for the concrete cores for each 25 mm (1.0 in) sample in the Corrosion Test Summary Report.



The level of chloride concentration in concrete at or near the depth of the steel reinforcement is used to estimate the condition of the steel (to determine whether it is corroding or not), and to determine the amount of concrete that would need to be removed during rehabilitation. It should be noted that cores taken at locations with cracks in the concrete or through delaminated areas generally have higher chloride concentrations compared to cores removed from non-cracked locations. For this reason, it is suggested that cores be taken at both sound locations as well as distressed locations to better assess the chloride level of the structure. The following rules of thumb are offered here for information only regarding chloride concentration and condition of reinforcing steel:

Chloride Concentration in Reinforced Concrete

ppm (kg/m <sup>3</sup> )	lb/yd <sup>3</sup>	Assumed Condition
0 to 0.7	0 to 1.2	Passive (not corroding)
0.9 to 1.8	1.2 to 3.0	Corrosion initiation
> 1.8	> 3.0	Active corrosion

## **14. MISCELLANEOUS TOPICS**

### **14.1 Stray Current Mitigation**

Stray current in the soil has been around since the first outdoor electrical installations. Although alternating current (AC) can cause corrosion, it is generally considered insignificant (more than a thousand times less) when compared to corrosion from direct current (DC).

Stray current corrosion (interference corrosion) is corrosion caused by direct current from an external source that travels through paths other than the intended circuit. Accelerated corrosion may result if the current is collected by a structure and leaves to enter the soil. Stray currents in bridge structure elements can be caused in two ways, either through direct connection or through a soil gradient.

Direct connection involves attaching a pipeline, electric railway track, or high-voltage contact system to bridge structure elements. Installation requires an approved insulator between the pipe or rail and the bridge element, and the high-voltage contact system requires double insulation for safety. Since concrete is not an insulator, a failed insulator, even if connected only to the concrete, will cause corrosion in bridge structure elements.

Discharging current into the soil produces soil gradients. The most common source is a cathodic protection system for a pipeline, which produces a steady DC voltage in the soil near the anode(s). By contrast, the DC soil voltage near a traction power substation (TPSS) is zero for a totally ungrounded TPSS, pulsing for a diode-grounded TPSS, and pulsing/reversing for some heavy rail TPSS.





Proposals for pipelines attached to bridge structures or located within two pipe diameters should be submitted for review. Also, notification of pipeline cathodic protection anode bed(s) located near a bridge (within one bridge length) should be included in the proposal.

Measures must be taken to mitigate possible stray current problems whenever they are anticipated or suspected. The DES Office of Electrical, Mechanical, Water, and Wastewater Engineering should be contacted to review proposals and to provide assistance in mitigating stray current problems.

The above considerations given for bridge structures also apply to long steel culverts and pipes.

#### **14.2 Dust Palliatives**

At some construction sites dust palliatives may be applied for dust control. Prior to application, it must be determined whether the dust palliative will create a corrosion problem or be deleterious to concrete due to salt content in the palliative. Chlorides in the dust palliative can cause corrosion of pavement dowels, reinforced concrete, or steel structures. Also, sulfates in the dust palliative can attack Portland cement concrete pavement or concrete structures. There can be high accumulations of sulfates and chlorides, particularly if the dust palliative is applied in multiple applications.

Contact the Corrosion and Structural Concrete Field Investigation Branch, if necessary for assistance related to the corrosion potential of dust palliative additives.

#### **14.3 Encroachment Permits**

If an encroachment permit application involves corrosion issues, the District Encroachment Permit office may request the Corrosion and Structural Concrete Field Investigation (CSCFI) Branch of METS to conduct a technical review. The CSCFI Branch can review the environmental conditions, materials, corrosion protection, and cathodic protection (if any) associated with the installation or construction. Although each project must be handled on a case-by-case basis, at a minimum, the applicant should submit supporting documentation to the District Encroachment Permit office such as plans and specifications for the project, cathodic protection details, soil and water corrosion test results, geologic logs of soil borings, etc.

Depending on the complexity of the project, it may take several weeks for the CSCFI Branch to conduct a thorough corrosion review of the corrosion-related aspects of the encroachment permit. Upon completion of the corrosion review, the CSCFI Branch will submit review comments to the District Encroachment Permit office. If the applicant has not included sufficient corrosion protection in the project, additional corrosion protection recommendations will be provided by the CSCFI Branch to the District Encroachment Permit office for the applicant.



#### **14.4 Miscellaneous Metals**

Miscellaneous metal parts and components are often used in roadway facilities and transportation structures. Fasteners, concrete anchors, plates, and frames are just a few examples. Typical corrosion protection includes zinc galvanizing in accordance with the *Standard Specifications*. However, in corrosive environments such as in coastal areas, the splash zone, or underwater, improved corrosion protection may be necessary. Stainless steel is often specified instead of galvanized steel. For critical components in corrosive environments, stainless steel Type 316 is preferred. Stainless steel Type 316 contains molybdenum that improves its corrosion protection over more commonly used stainless steels such as Type 304.

If you have questions regarding materials selection for miscellaneous metal parts and components, contact the Corrosion and Structural Concrete Field Investigation Branch of METS for assistance.



## 15. REFERENCES

The following corrosion references are taken from various Department documents and are presented here for the convenience of the users of these guidelines.

1. *Standard Specifications* (<http://www.dot.ca.gov/hq/esc/oe/standards.php>).
2. *Highway Design Manual, Chapter 850, Physical Standards* (<http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm>).
3. *2006 Geotechnical Design Reports* (<http://www.dot.ca.gov/hq/esc/geotech/requests/gdrguidelines20061220.pdf>).
4. *Bridge Memo-To-Designers* (<http://www.dot.ca.gov/hq/esc/techpubs>).
5. *Structure Reference Specifications* (<http://www.dot.ca.gov/hq/esc/structurespecs>).
6. *California Amendments (to the AASHTO LRFD Bridge Design Specifications - Fourth Edition)* ([http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/ca-to-aashto-lrfd-bds/page/sec\\_5\\_2011.pdf](http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/ca-to-aashto-lrfd-bds/page/sec_5_2011.pdf)).
7. *Bridge Design Specifications, Section 4, Foundations* (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-design-specifications/bds.html>).
8. *Memo To Designers, 3-1, Corrosion, Deep Foundations* (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%203/3-1.pdf>).
9. *Memo To Designers, 10-5, Protection of Reinforcement Against Corrosion Due to Chlorides, Acids, and Sulfates* (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%2010/10-5.pdf>).
10. *Memo To Designers 10-6, Use of Prefabricated Epoxy Coated Reinforcement in Marine Environment* (<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%2010/10-6.pdf>).
11. *Standard Special Provision SSP 87-2 (A05-20-11), Slag Aggregate, Districts 7, 8, 11 and 12* (<http://www.dot.ca.gov/hq/esc/oe/standards.php>).
12. *Standard Specifications Section 54, Waterproofing* (<http://www.dot.ca.gov/hq/esc/oe/standards.php>).



13. ***Structures Reference Specification 50-560 (50TIEB), Tieback Anchors***  
(<http://www.dot.ca.gov/hq/esc/structurespecs/bridge/06specs/>).
14. ***Structures Reference Specification, 50-570 (50-TIED), Tiedown Anchors***  
(<http://www.dot.ca.gov/hq/esc/structurespecs/bridge/06specs/>).
15. ***Structures Reference Specification, 19-600 (19NAIL), Soil Nail Assembly***  
(<http://www.dot.ca.gov/hq/esc/structurespecs/bridge/06specs/>).
16. ***Bridge Construction Memo 145-8.0, Mechanically Stabilized Embankment Wall Construction Checklist, June 28, 2006***  
(<http://www.dot.ca.gov/hq/esc/construction/manuals/OSCCompleteManuals/BCRPVol2.pdf>).
17. ***Alternative Pipe Culvert Selection (ALTPPIPE)***  
(<http://www.dot.ca.gov/hq/oppd/altpipe.htm>).
18. ***California Test 643, Method for Determining Field and Laboratory Resistivity and pH measurements for Soil and Water*** (<http://www.dot.ca.gov/hq/esc/ctms/index.html>).
19. ***California Test 422, Method of Testing Soils and Waters for Chloride Content***  
(<http://www.dot.ca.gov/hq/esc/ctms/index.html>).
20. ***California Test 417, Method of Testing Soils and Waters for Sulfate Content***  
(<http://www.dot.ca.gov/hq/esc/ctms/index.html>).
21. ***California Test 404, Test Method for the Chemical Analysis of Portland Cement Concrete, Fly Ash, Pozzolan, and Blended Cement***  
(<http://www.dot.ca.gov/hq/esc/ctms/index.html>).
22. ***California Test 125, Method of Test for Sampling Highway Materials and Products Used in the Roadway Structural Sections***  
(<http://www.dot.ca.gov/hq/esc/ctms/index.html>).